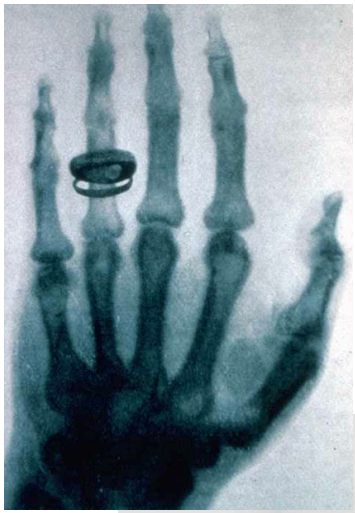
Introduction to X-ray phase-contrast and dark-field imaging

Martin Bech

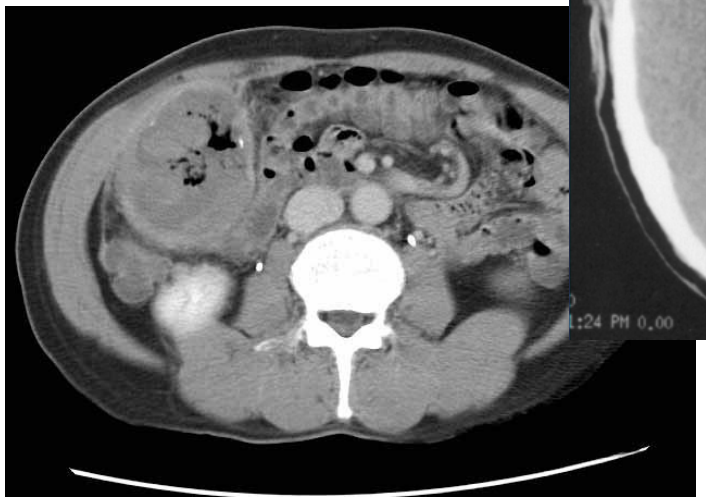
Lund University
Department medical radiation physics
martin.bech@med.lu.se

High Contrast / Low Contrast



First x-ray image
made by Röntgen in 1896

Modern x-ray image
2011



Coherent X-ray imaging using Synchrotron Radiation

» What is so special about Synchrotron Radiation?

Coherence

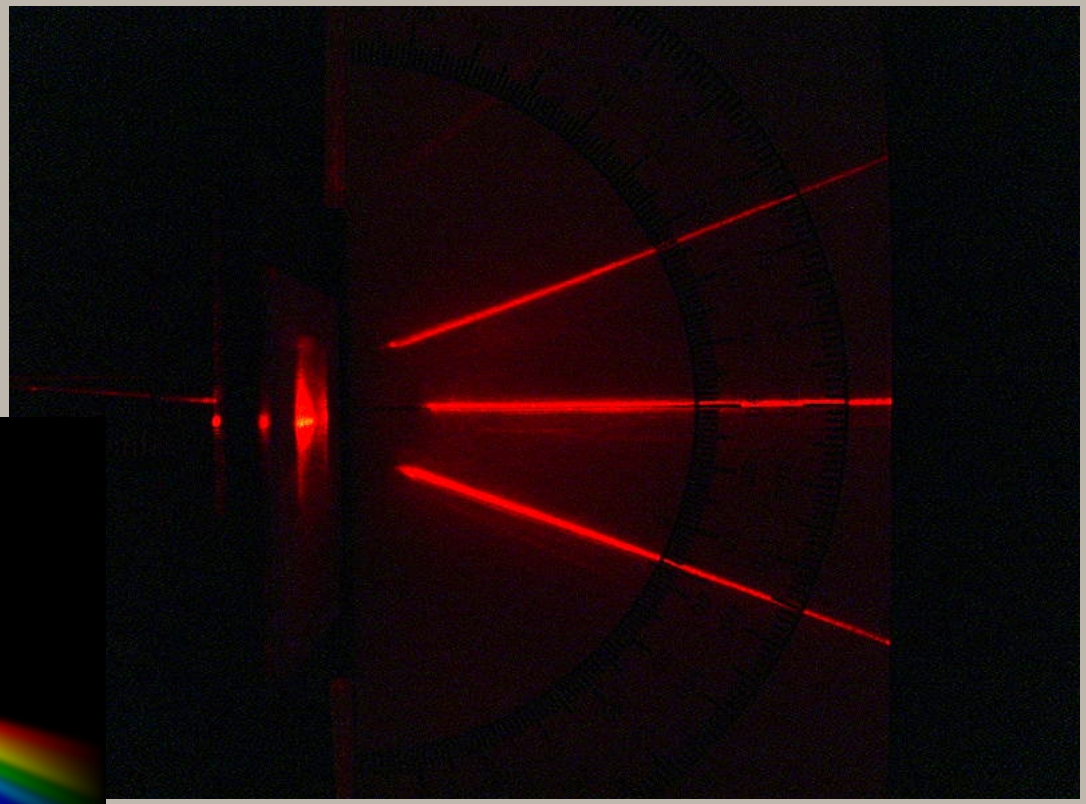
» and how do we use it for better X-ray imaging?

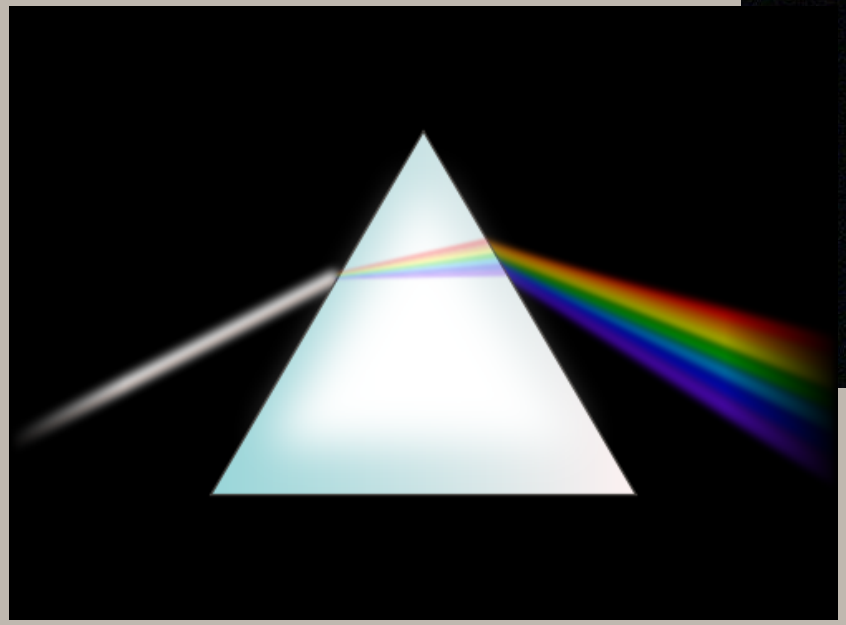
Phase contrast

LUND UNIVERSITY

Analogy – Visible Light

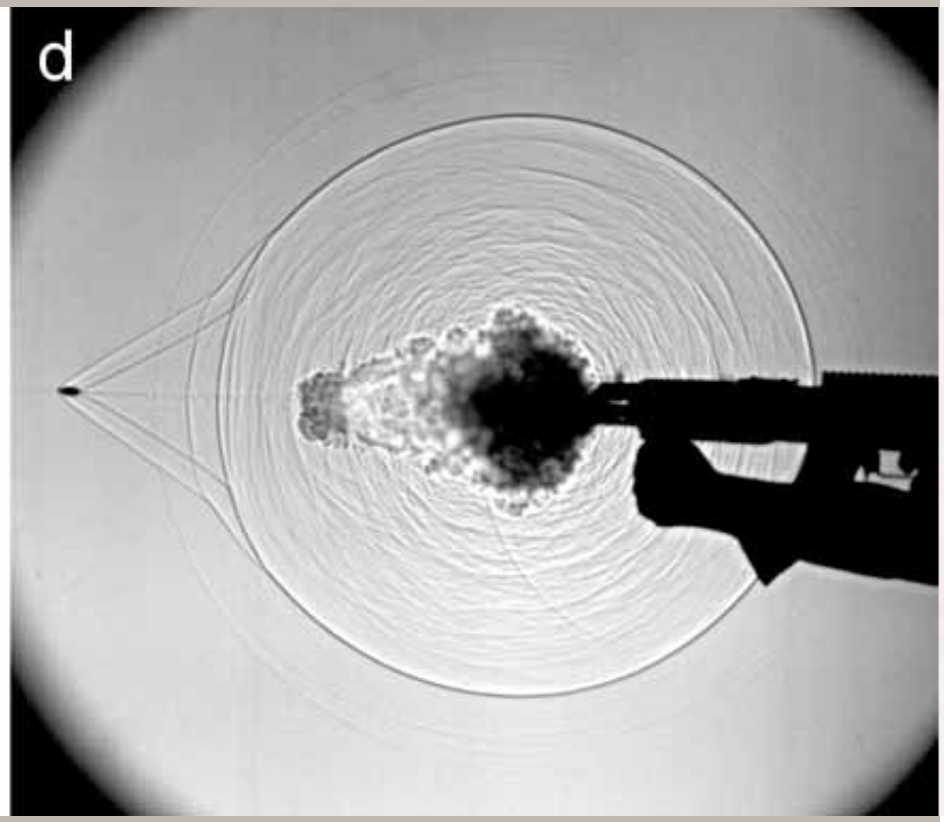
- Diffraction
- Refraction





LUND UNIVERSITY

Analogy – Visible Light



Wikipedia: (images by Gary S. Settles, Penn State Gas Dynamics Lab)

Phase contrast imaging

LUND UNIVERSITY

Imaging regimes

Fresnel number:

$$F = \frac{a^2}{\lambda d}$$

a is the feature size in the sample,

d is the distance from sample to point of measurement

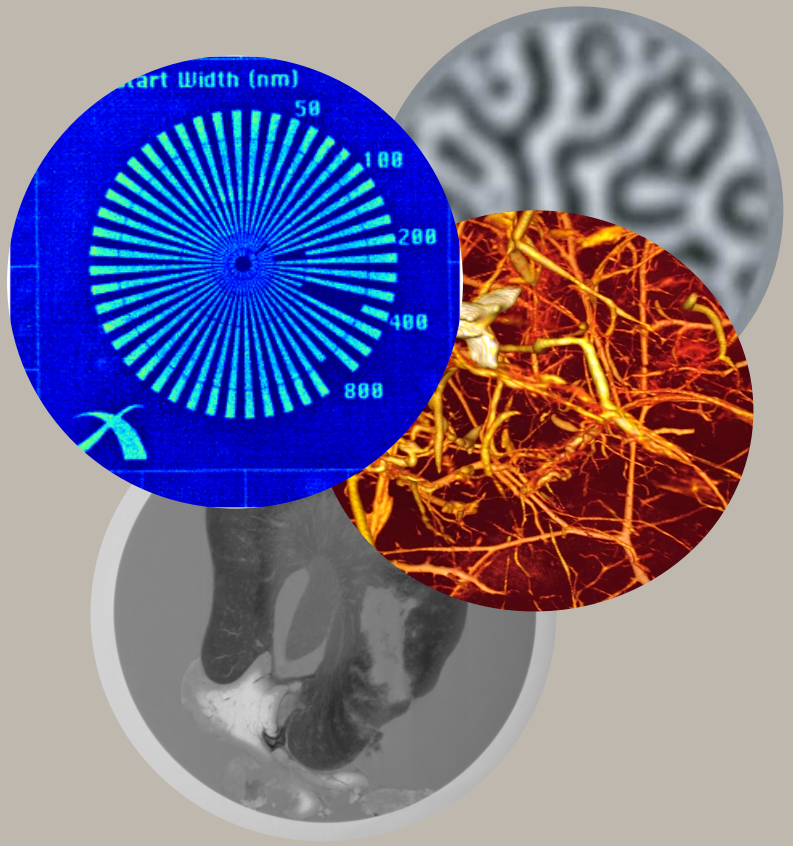
F << 1 *Far-field regime (Fraunhofer)*

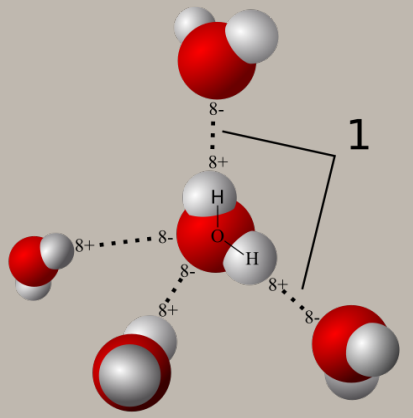
$F \approx 1$ *Near-field regime (Fresnel)*

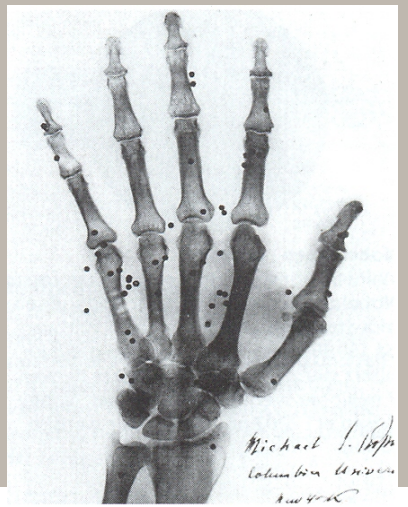
F >> 1 *Contact regime*

Imaging at different length scales

- Atomic
- Microscopic
- Macroscopic







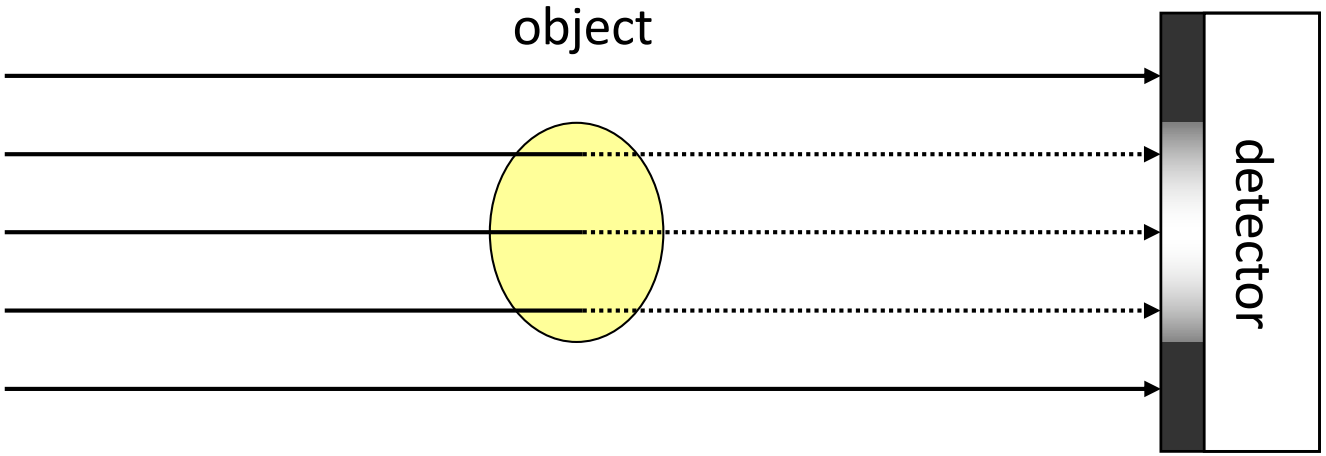
Three signals for imaging

Absorption – Standard x-ray image

Refraction – Phase-contrast image

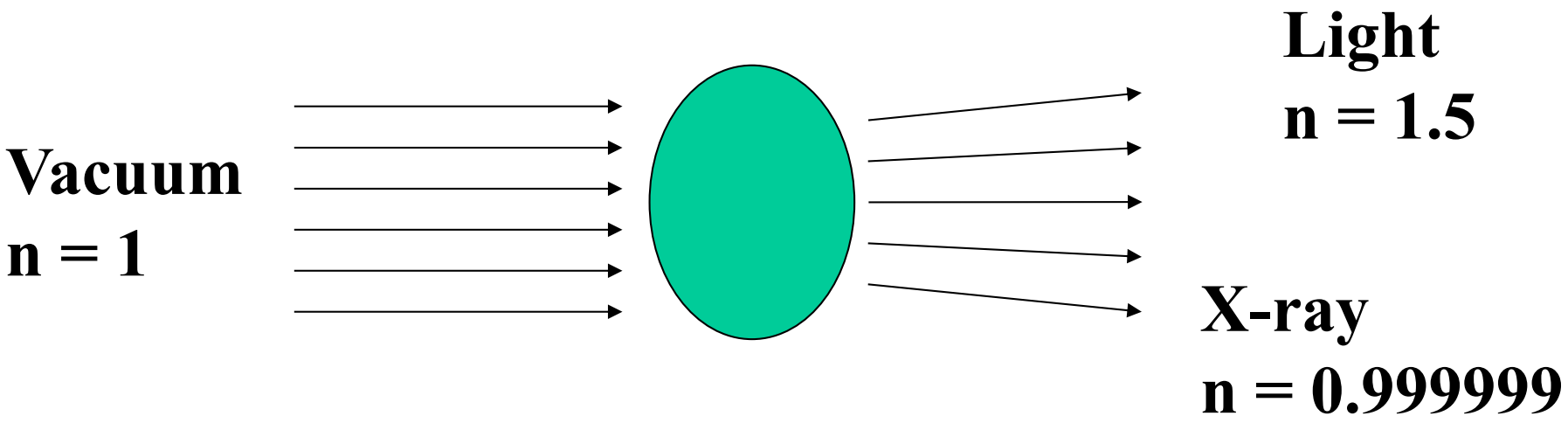
Scattering – Dark-field image

Conventional X-Ray Radiography: Absorption Contrast

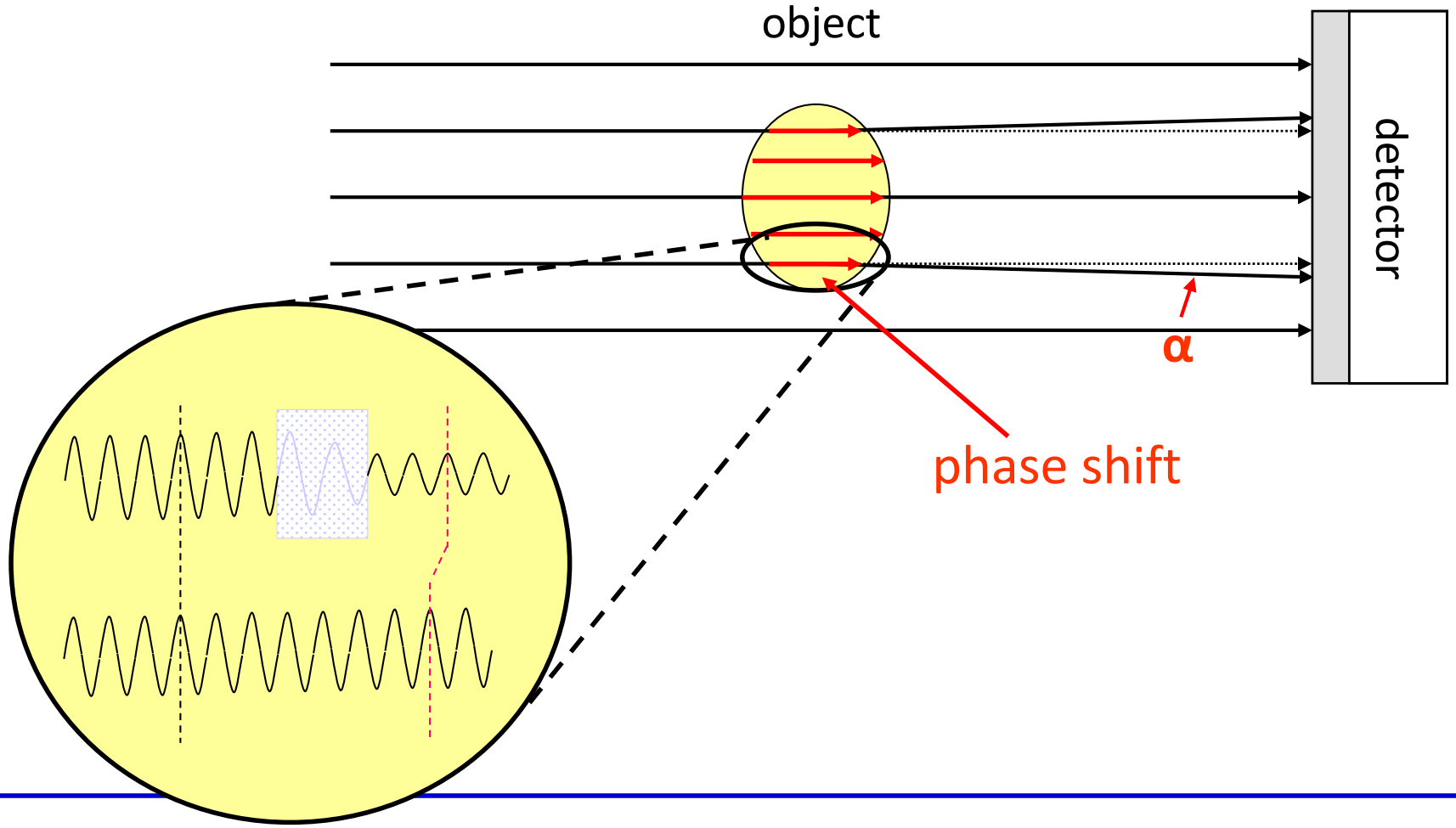


Refractive Index

Refraction in a lens

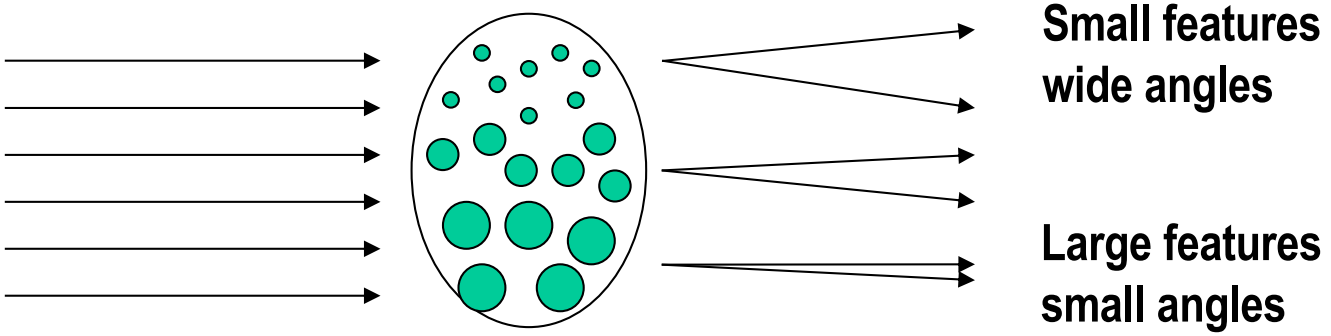


‘Wave-Optical’ X-ray Radiography: Phase Contrast



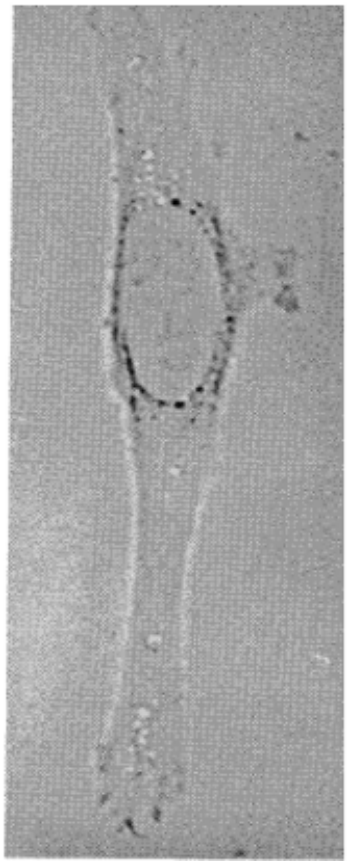
Scattering

SAXS - Small Angle X-ray Scattering

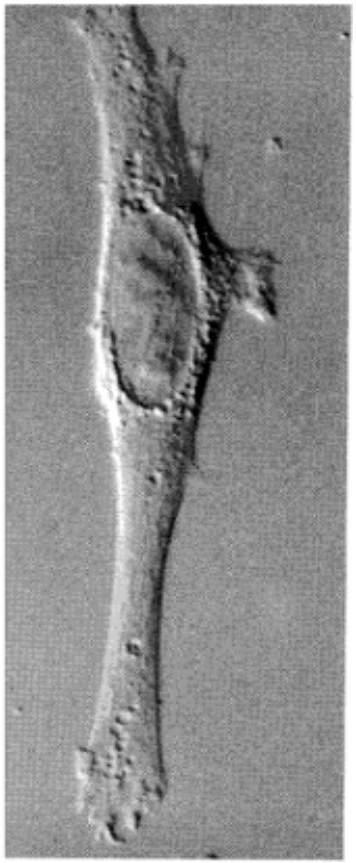


Visible light: Several contrast modalities

Zeiss microscope
www.zeiss.de



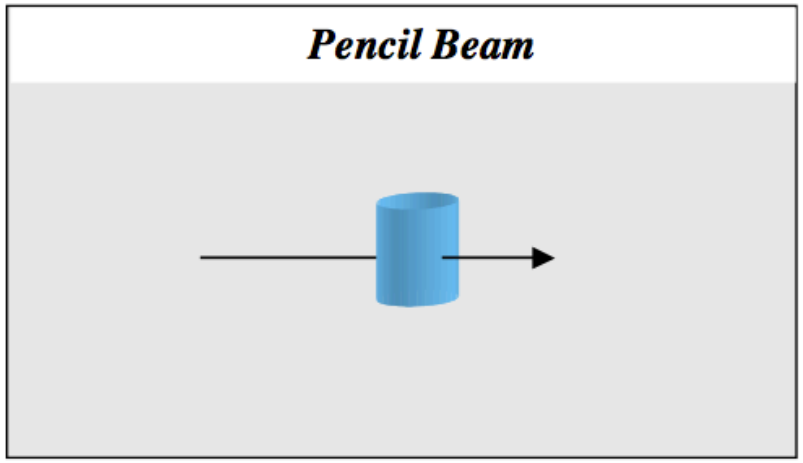
bright-field
contrast

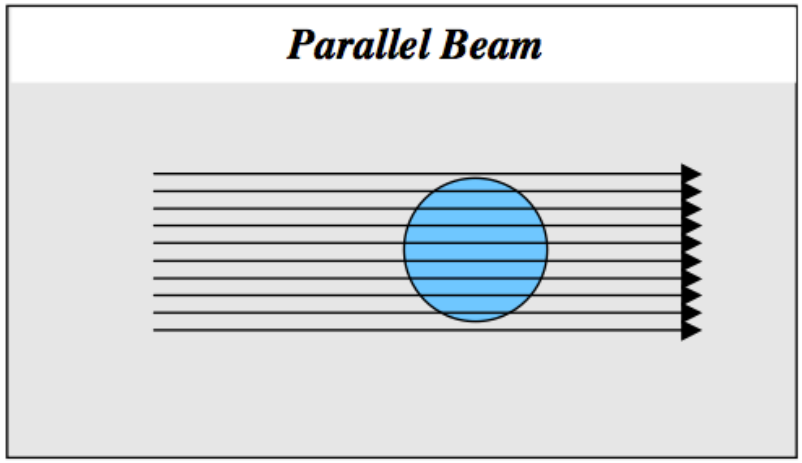


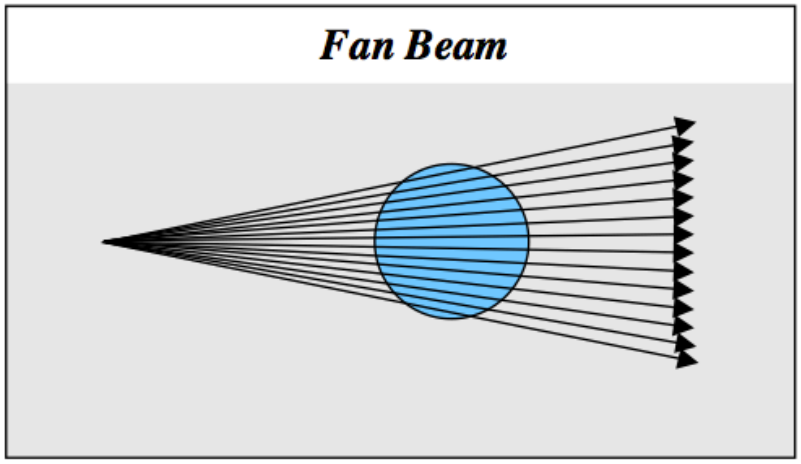
phase-contrast
(DIC)

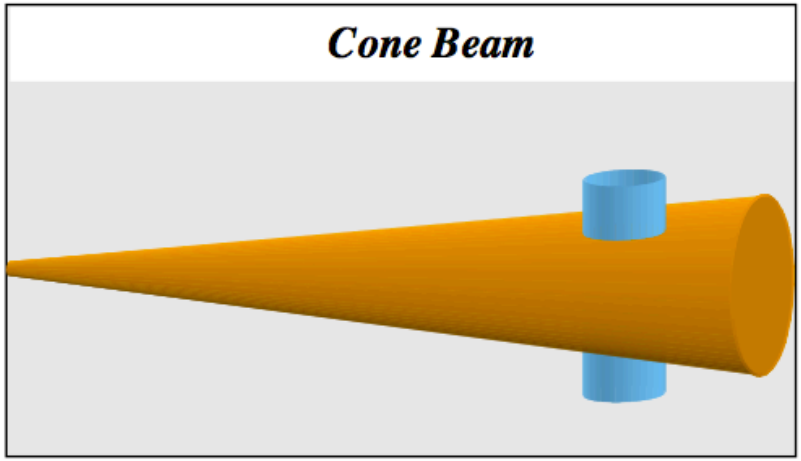
dark-field
contrast

Full field vs pencil beam









STXM : Scanning Transmission X-ray Microscopy

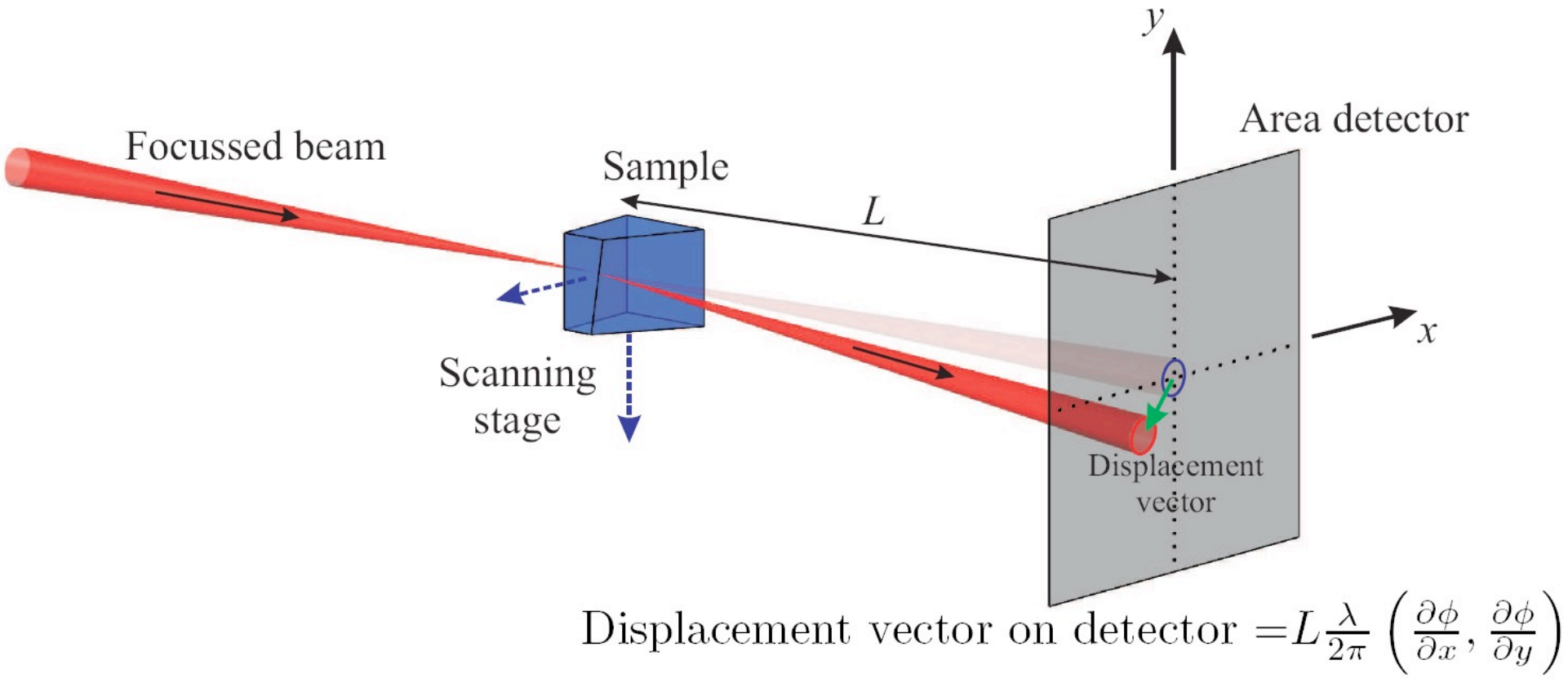
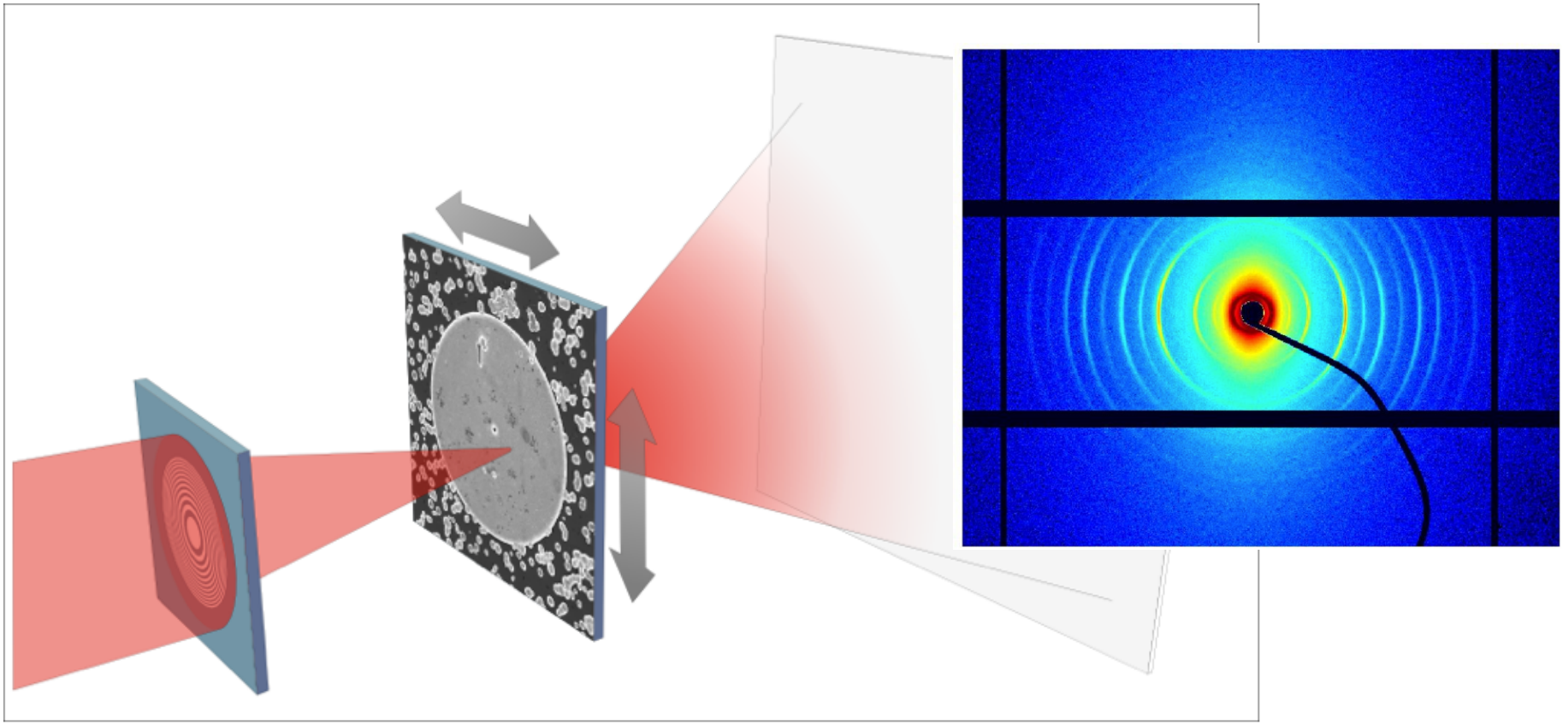


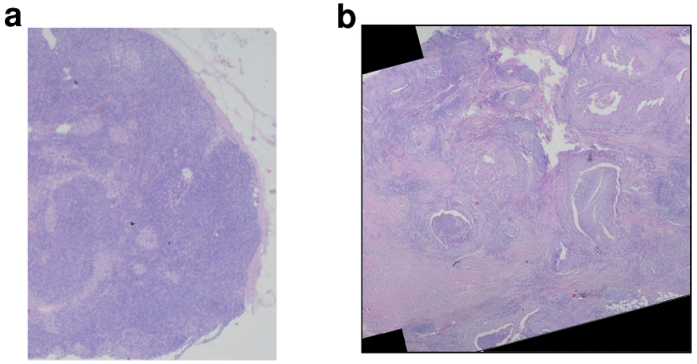
Figure courtesy: Jens Als-Nielsen

SAXS : Small Angle X-ray Scattering



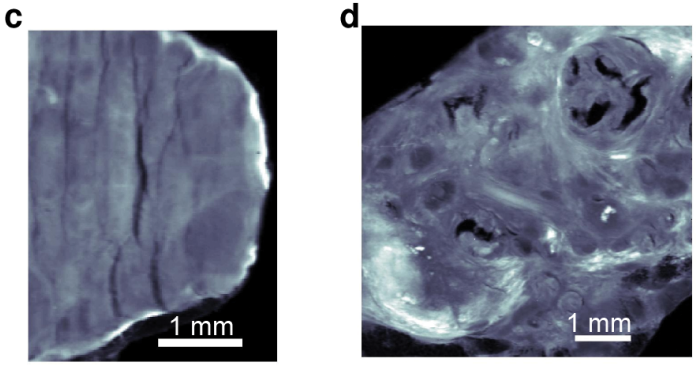
SAXS, Lymph nodes

Histology



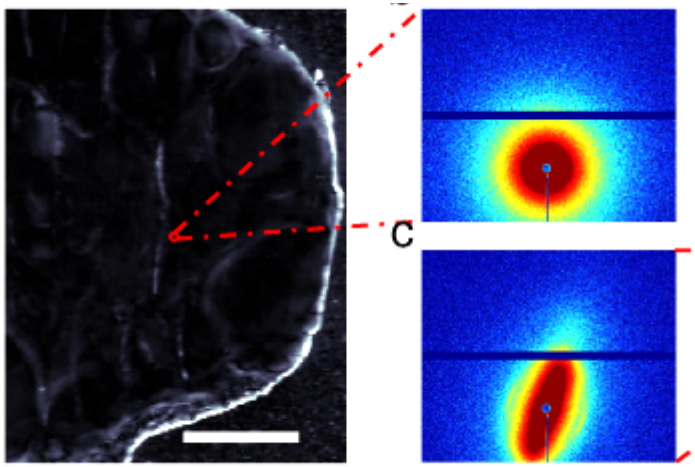
Healthy Invaded

Total scattered intensity



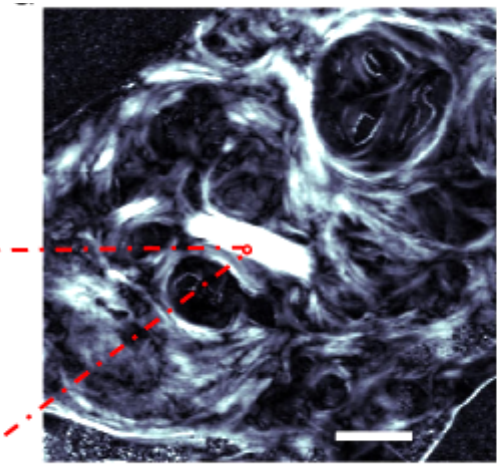
Healthy Invaded

Scattering assymetry



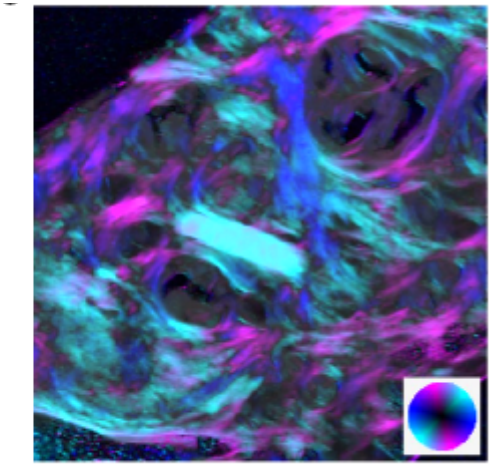
Healthy

Scattering assymetry



Invaded

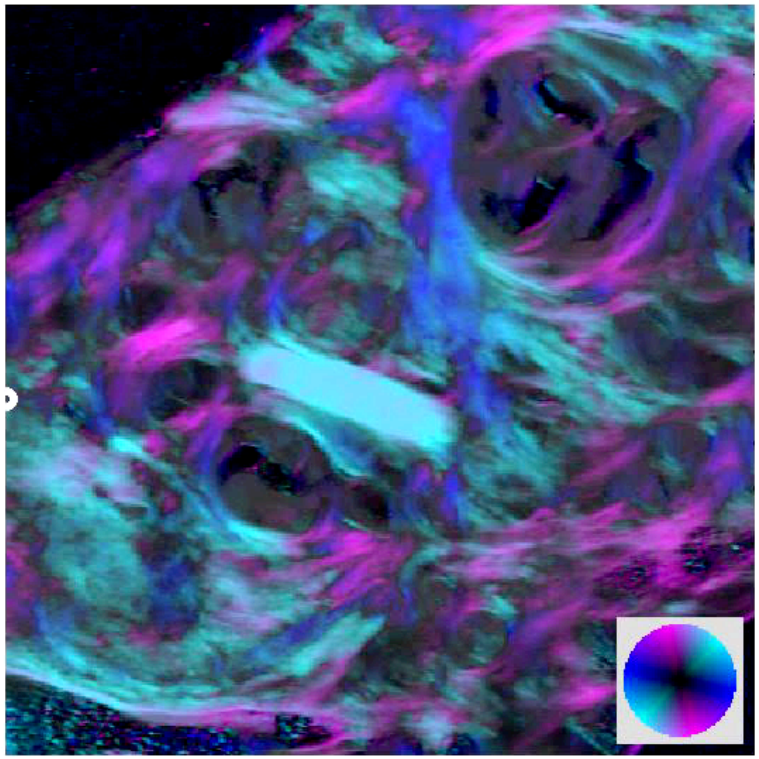
Scattering direction

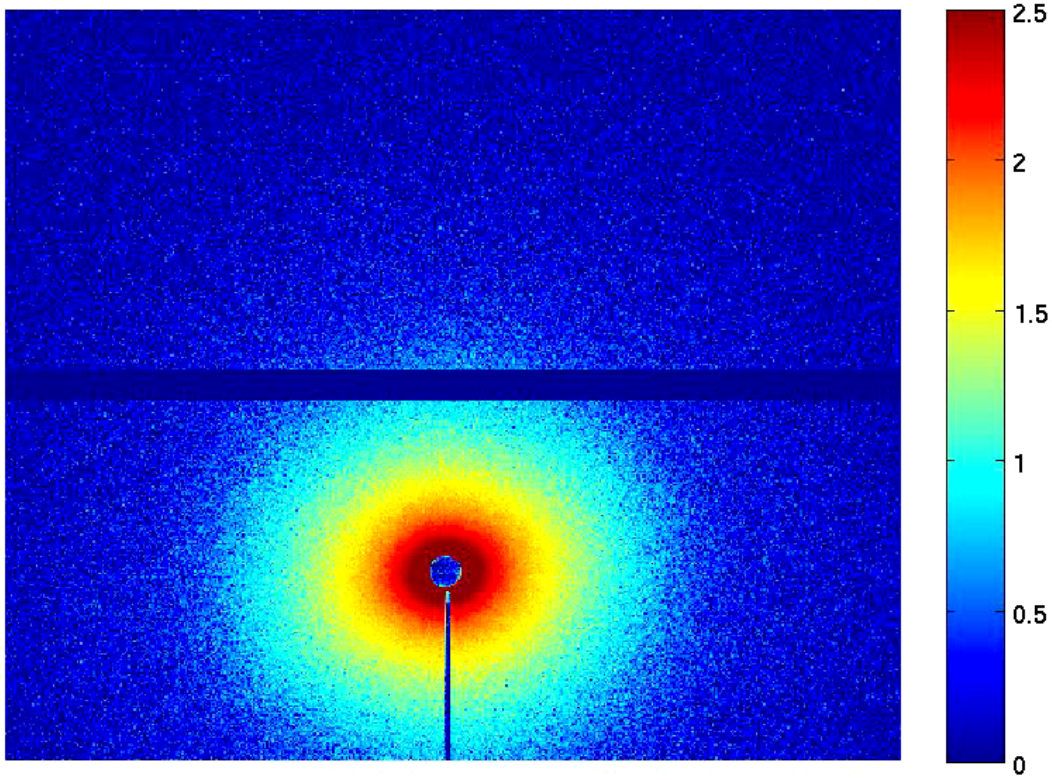


Invaded

SAXS

Small Angle X-ray Scattering





SAXS imaging

IOP PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **56** (2011) 1717–1726 doi:10.1088/0031-9155/56/6/012

Brain tumor imaging using small-angle x-ray scattering tomography

Torben H Jensen[1], Martin Bech[2], Oliver Bunk[3], Maria Thomsen[1], Andreas Menzel[3], Audrey Bouchet[4,5], Géraldine Le Duc[4], Robert Feidenhans'l[1] and Franz Pfeiffer[2]

[1] Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark
[2] Department of Physics, Technische Universität München, 85748 Garching, Germany
[3] Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
[4] European Synchrotron Radiation Facility, 38043 Grenoble, France
[5] Grenoble Institute of Neurosciences (Team 7), 38000 Grenoble, France

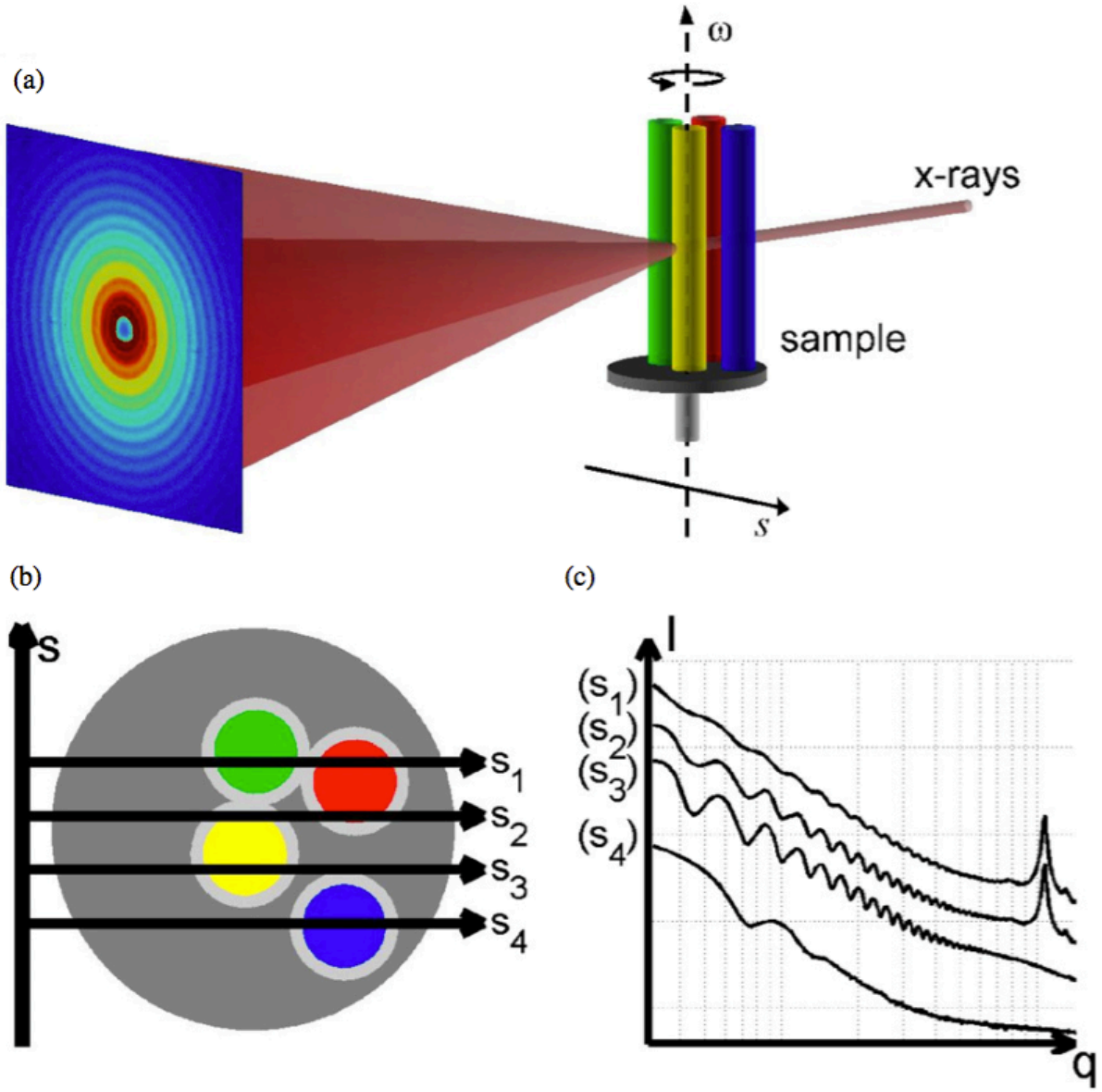


Figure 1. Small-angle x-ray scattering tomographic set-up. (a) Using a pencil-beam, scattering patterns are collected by translating the sample through the beam (s), for different orientations (ω). (b)–(c) An example with scattering patterns collected for four different projections are shown.

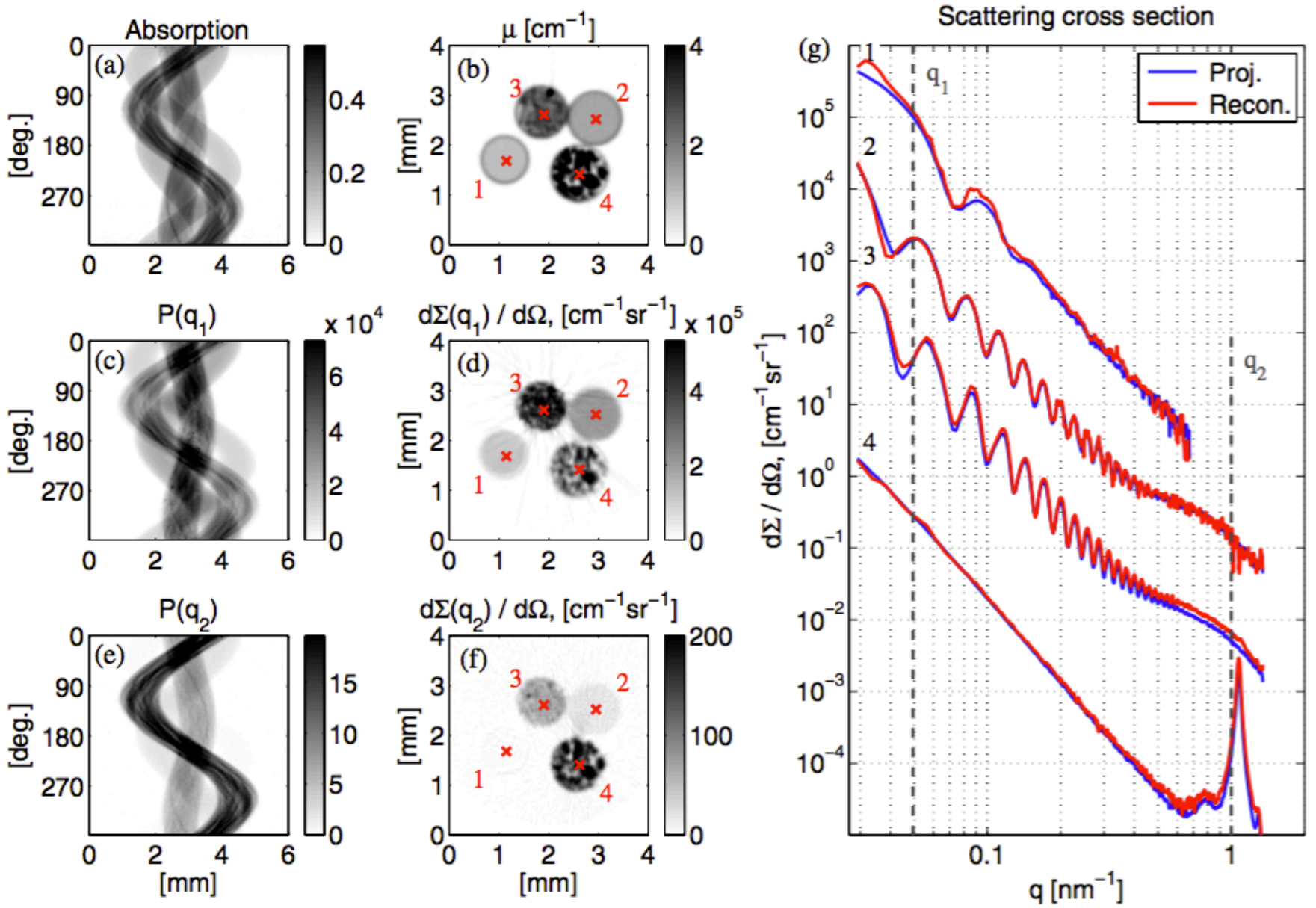
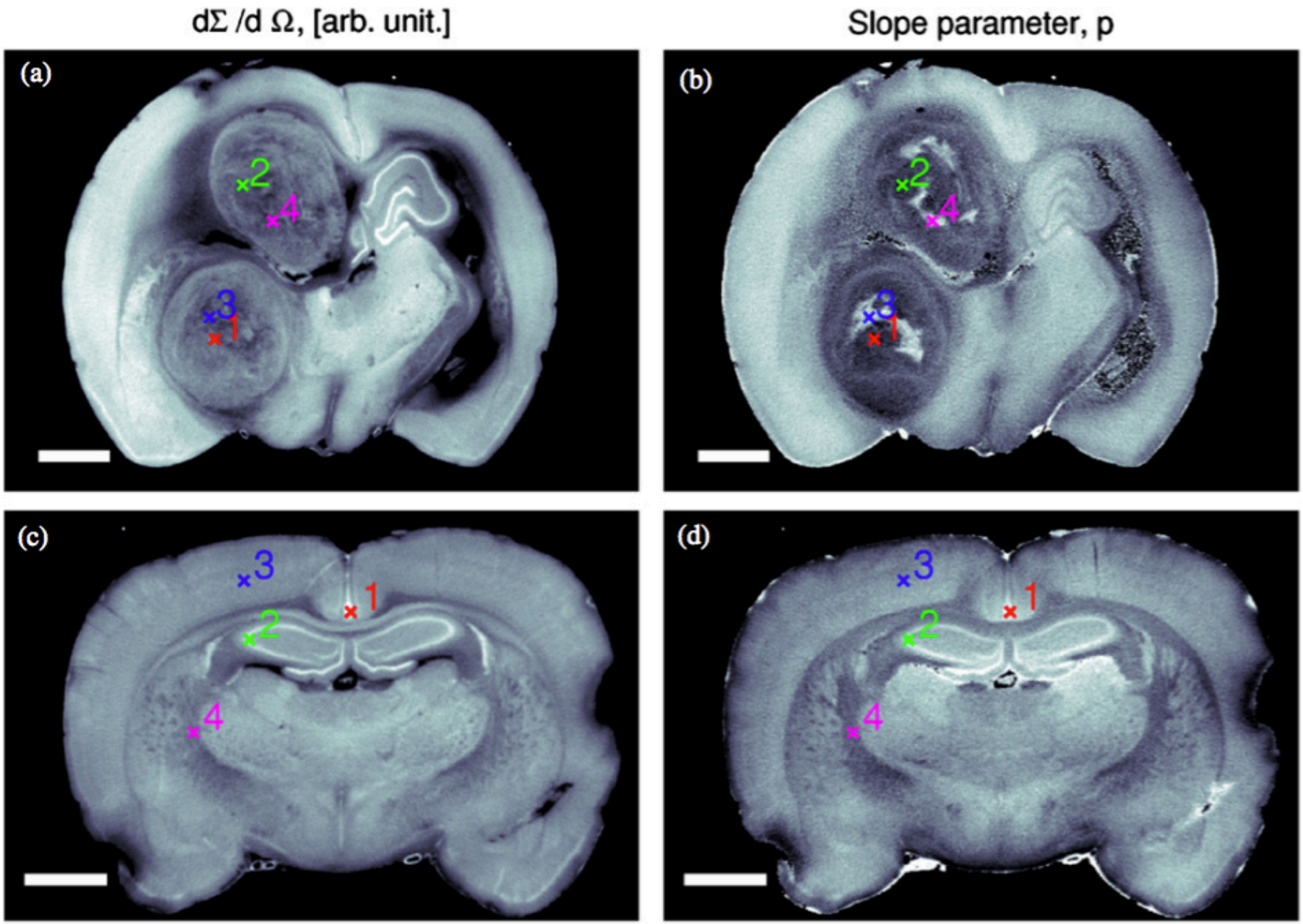


Figure 2. Sinograms and reconstructions. SAXS-CT was performed on a phantom consisting of


dΣ /d Ω, [arb. unit.]
Slope parameter, p
(a)
(b)
(c)
(d)
1
2
3
4

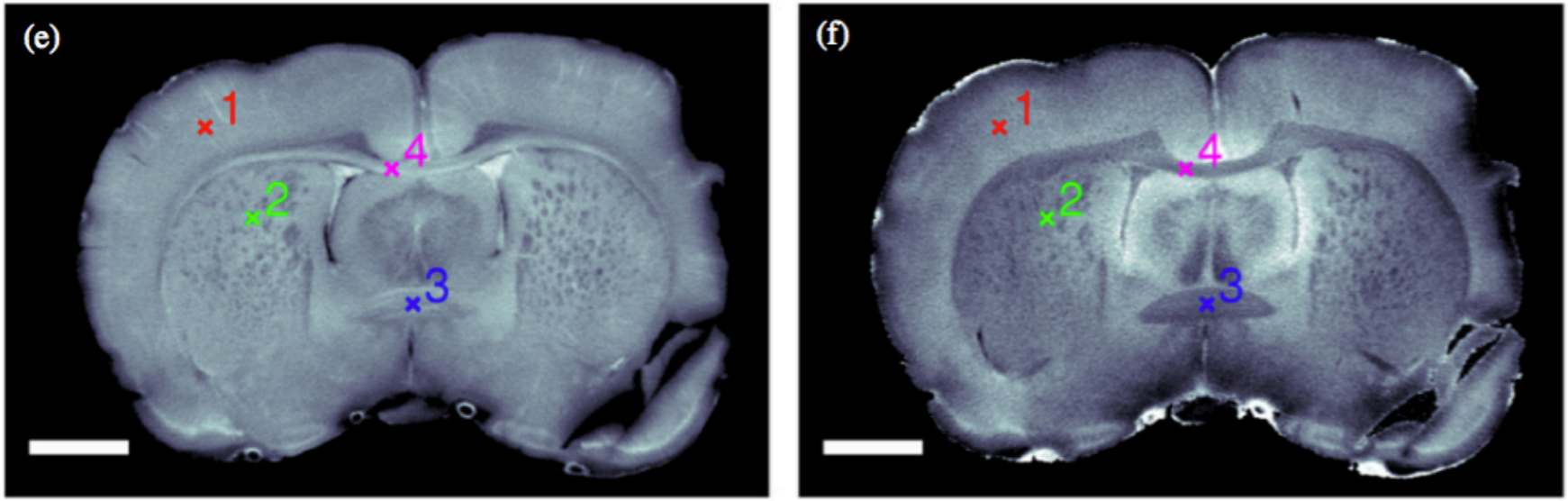


Figure 3. Biological example, rat brain. The three rows, each represent three different tomographic sections of two rat brains. The first column (panels (a), (c) and (e)) shows the local scattering cross section in the q-range $q \in [0.071–0.16]$ nm^{-1} for the first row and in the q-range $q \in [0.071–0.39]$ nm^{-1} for the second and third row. The second column (panels (b), (d) and (f)) shows the local slope of the scattering curve in the same q-ranges. The scattering curves corresponding to the points marked in this figure are plotted in figure 4. The scale bars have a length of 2 mm. All images are displayed with a linear grayscale, with the following limits: (a) [5.9–25.3] arb. unit, (b) [1.34–2.52], (c), (e) [8.2–34.2] arb. unit and (d), (f) [1.80–2.51].

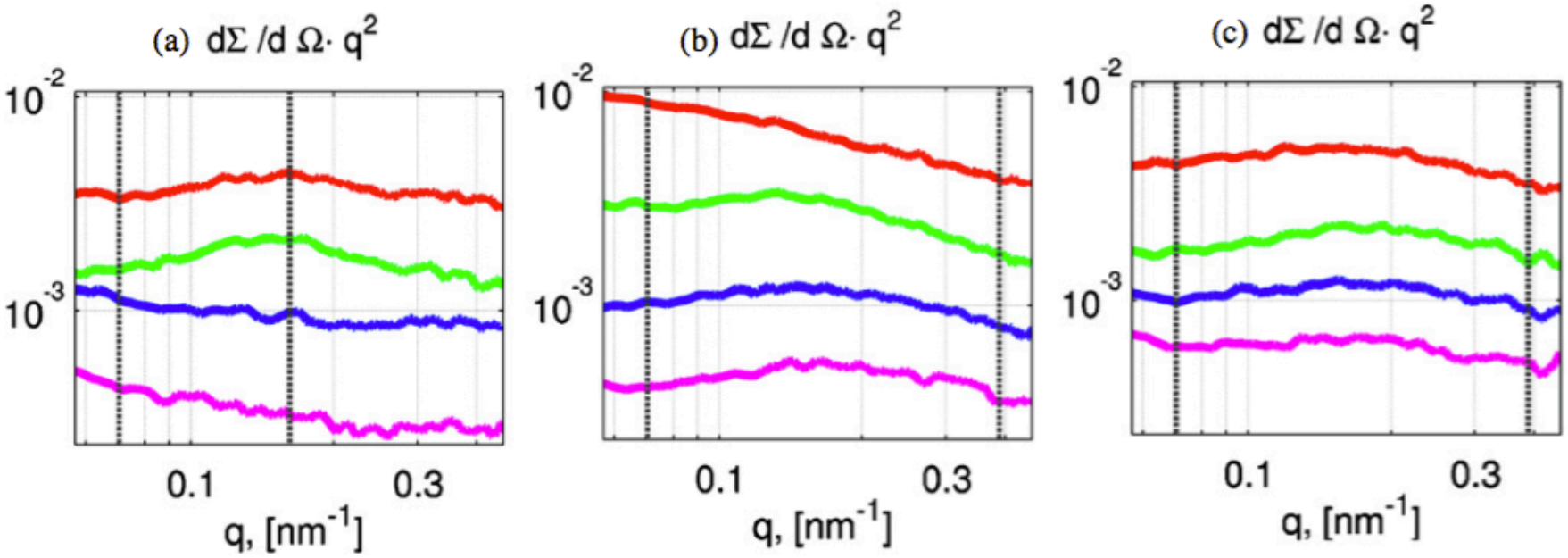


Figure 4. Biological example, rat brain. Panels (a), (b) and (c) show the reconstructed small-angle scattering curves for four selected points from each of the rows in figure 3. The panels (a), (b) and (c) correspond to row 1, 2 and 3, respectively. The correspondence between the points in figure 3 and the scattering curves in this figure is shown by color and numbering. Each scattering curve is offset by a factor of 2 for clarity.

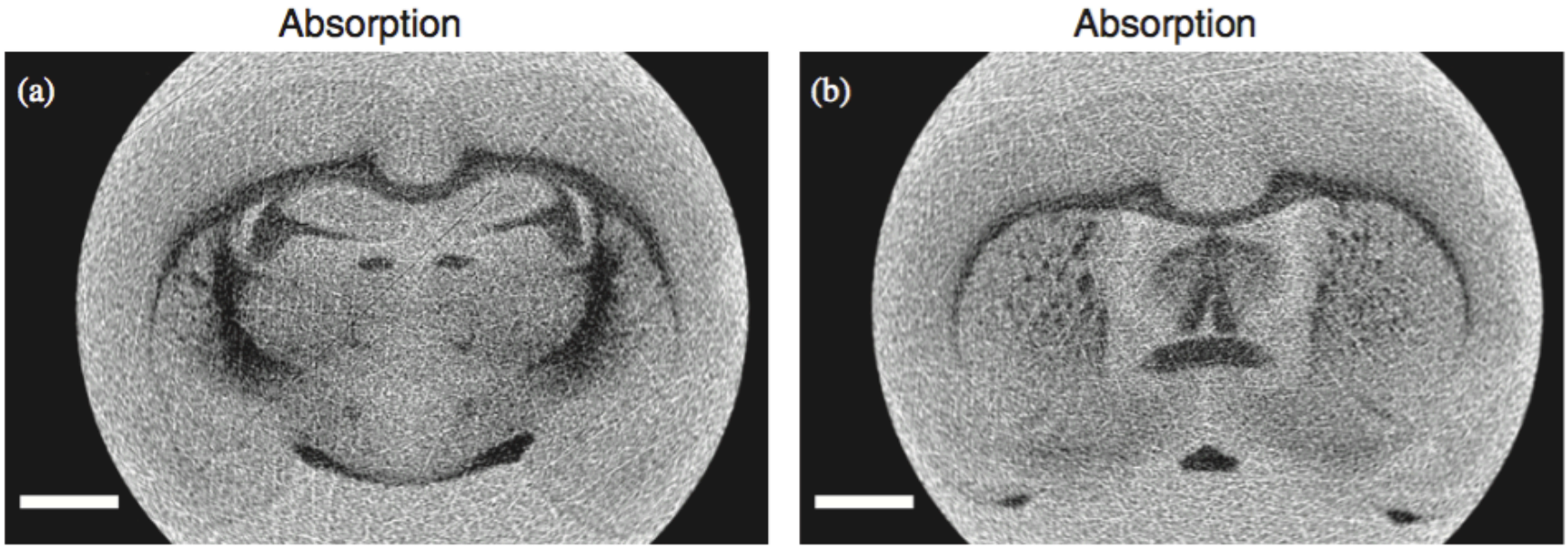
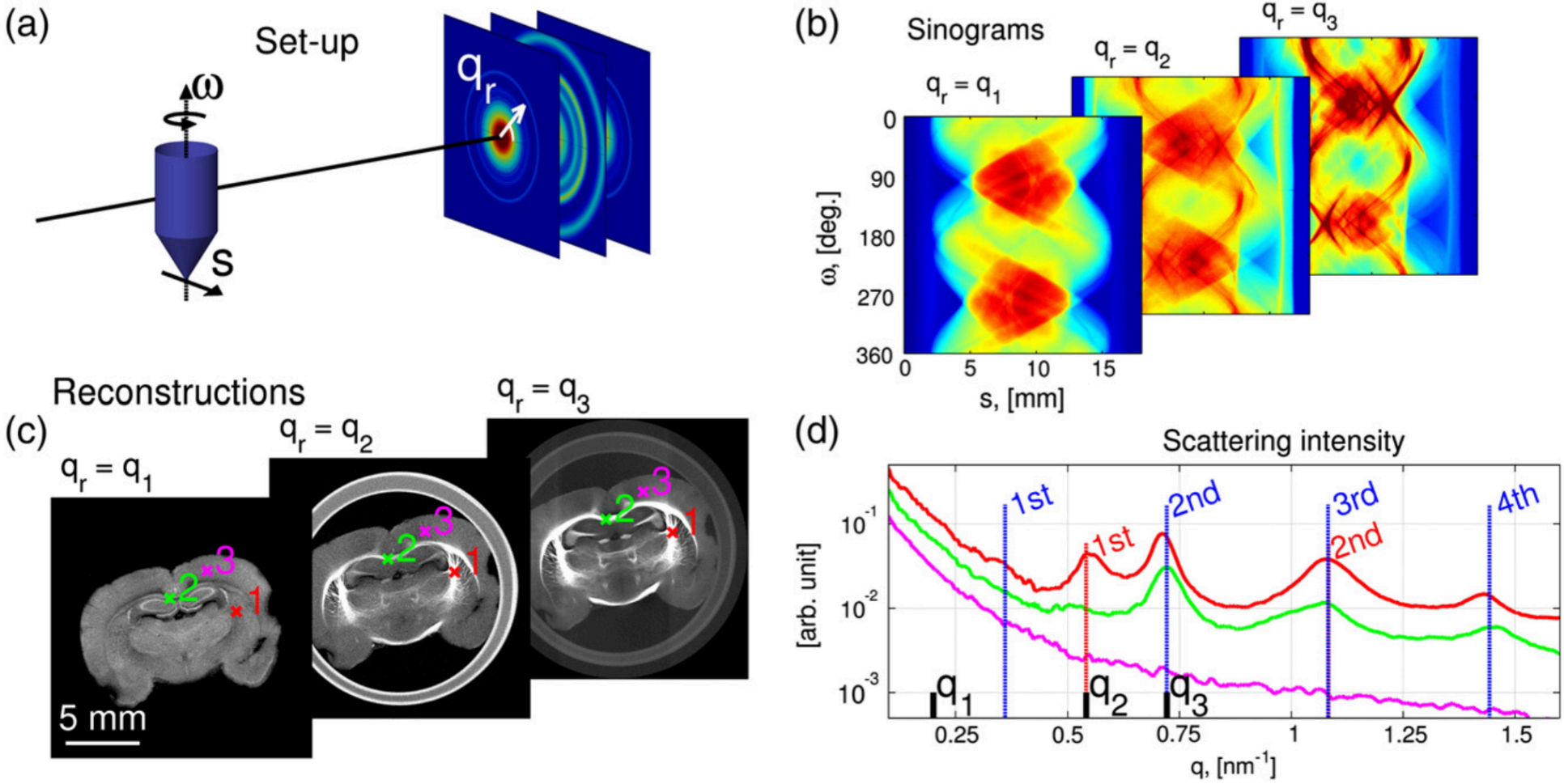


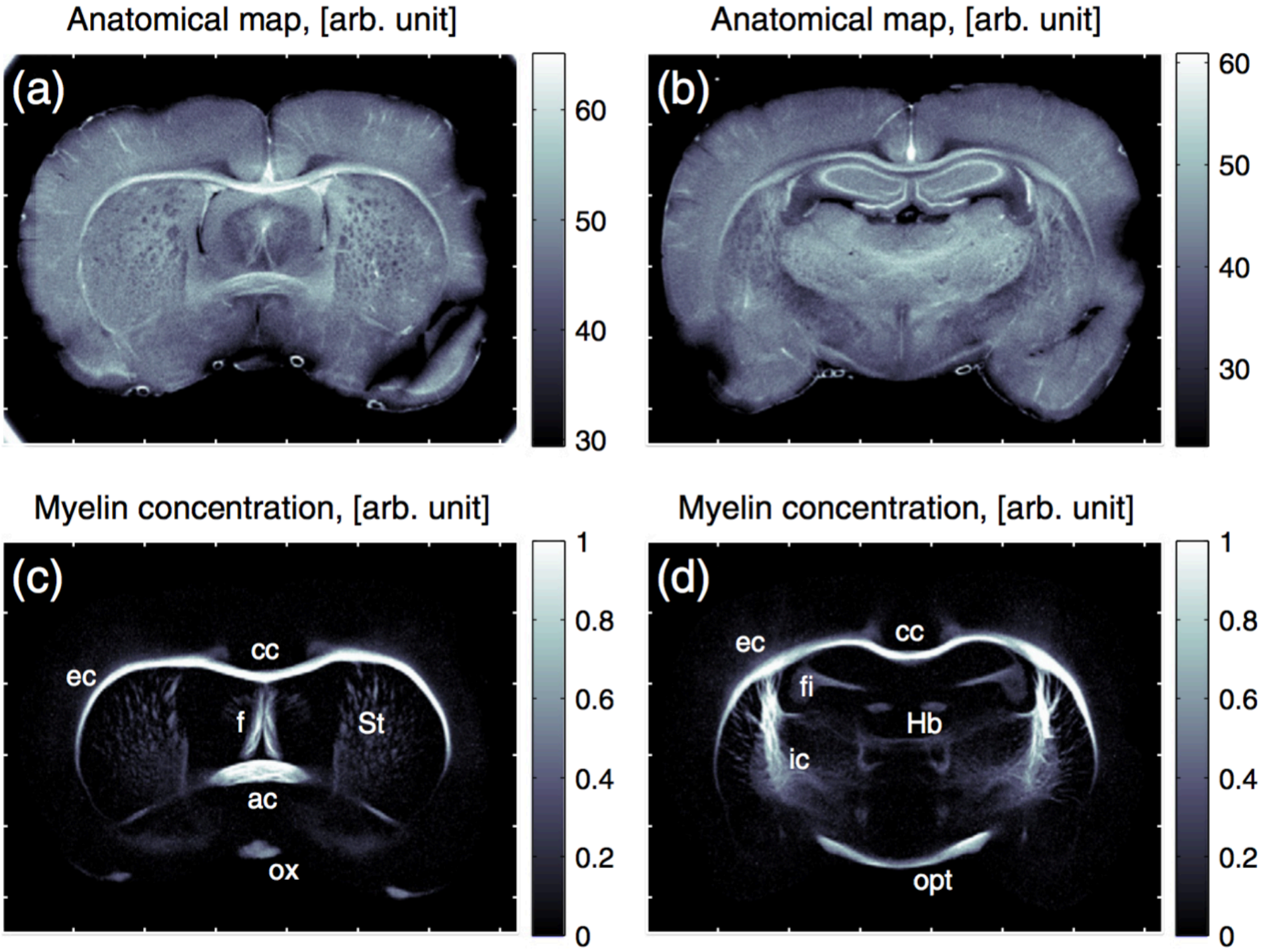
Figure 5. Biological example, rat brain. Panels (a) and (b) show the absorption images corresponding to slices (c), (d) and (e), (f) of figure 3, respectively. The scale bars have a length of 2 mm. Both images are displayed with a linear grayscale of [0.83–0.93] cm^{-1}.

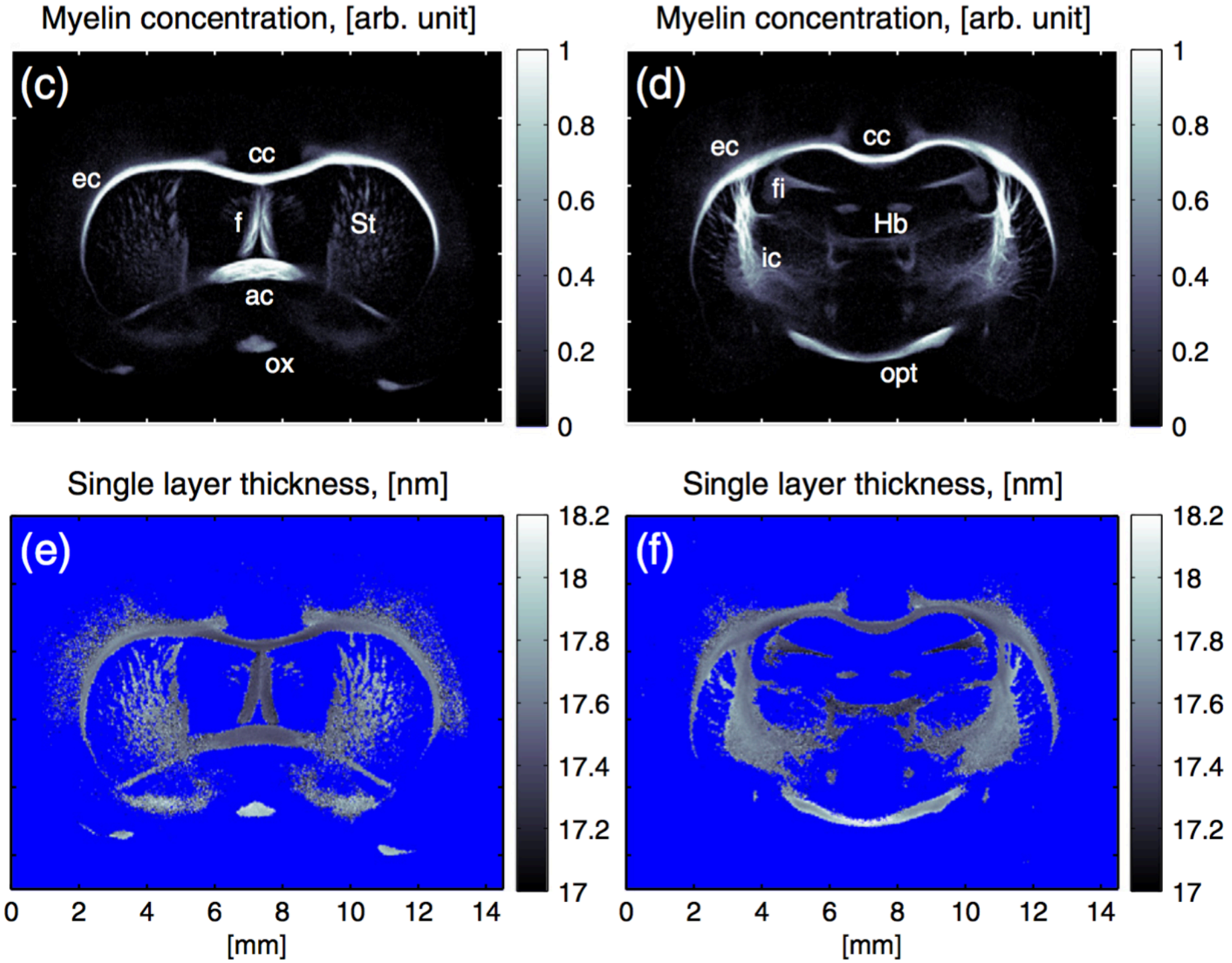
Molecular X-ray computed tomography of myelin in a rat brain

T.H. Jensen [a,*], M. Bech [a,b], O. Bunk [c], A. Menzel [c], A. Bouchet [d,e], G. Le Duc [d], R. Feidenhans'l [a], F. Pfeiffer [b]

[a] *Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
[b] *Department of Physics, Technische Universität München, Garching, Germany*
[c] *Paul Scherrer Institut, Villigen PSI, Switzerland*
[d] *European Synchrotron Radiation Facility, Grenoble, France*
[e] *Grenoble Institute of Neurosciences (Team 7), Grenoble, France*

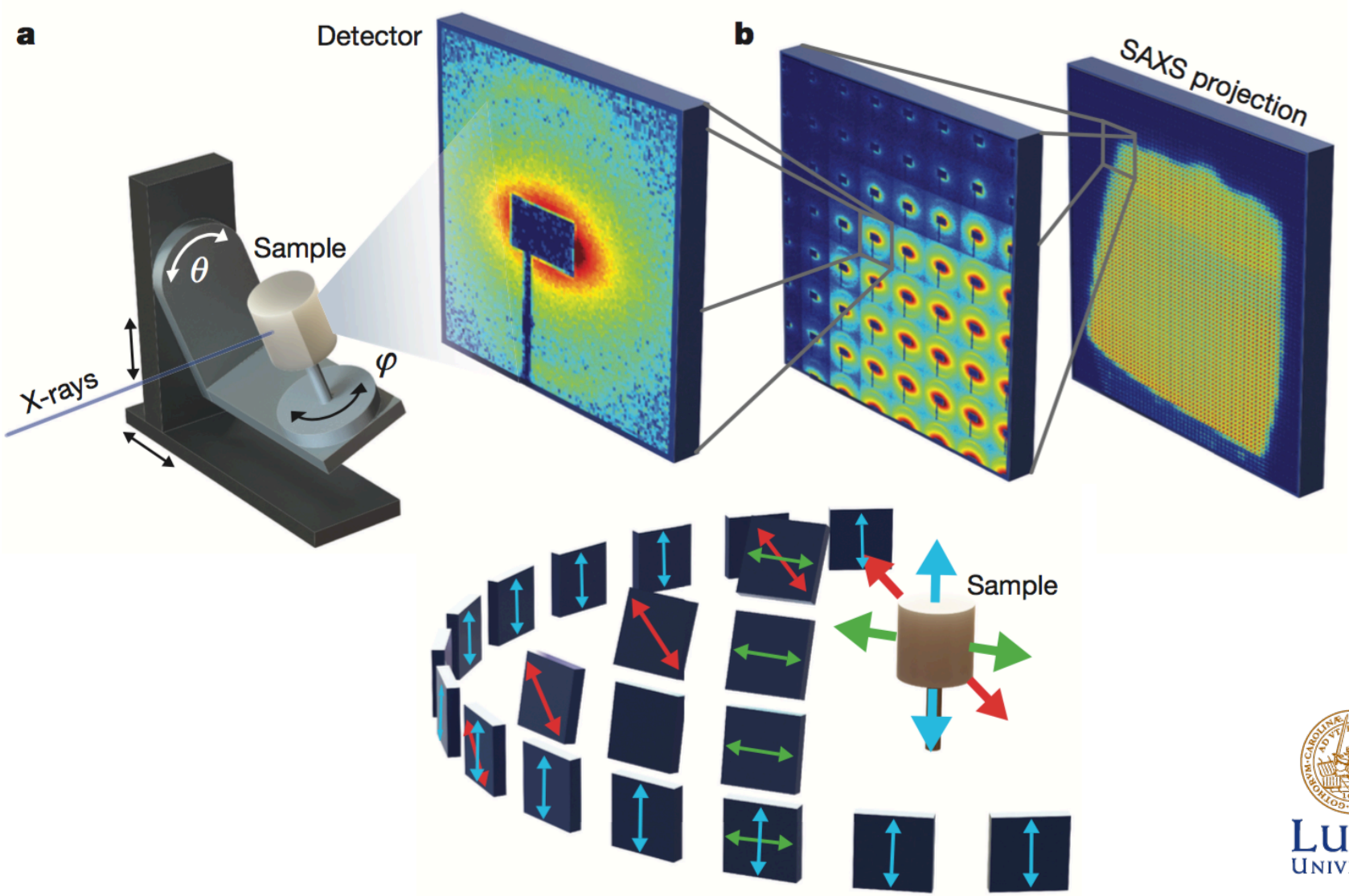



Anatomical map, [arb. unit]
(a)
60
50
40
30
Anatomical map, [arb. unit]
(b)
60
50
40
30
Myelin concentration, [arb. unit]
(c)
cc
ec
f
St
ac
ox
1
0.8
0.6
0.4
0.2
0
Myelin concentration, [arb. unit]
(d)
ec
cc
fi
Hb
ic
opt
1
0.8
0.6
0.4
0.2
0

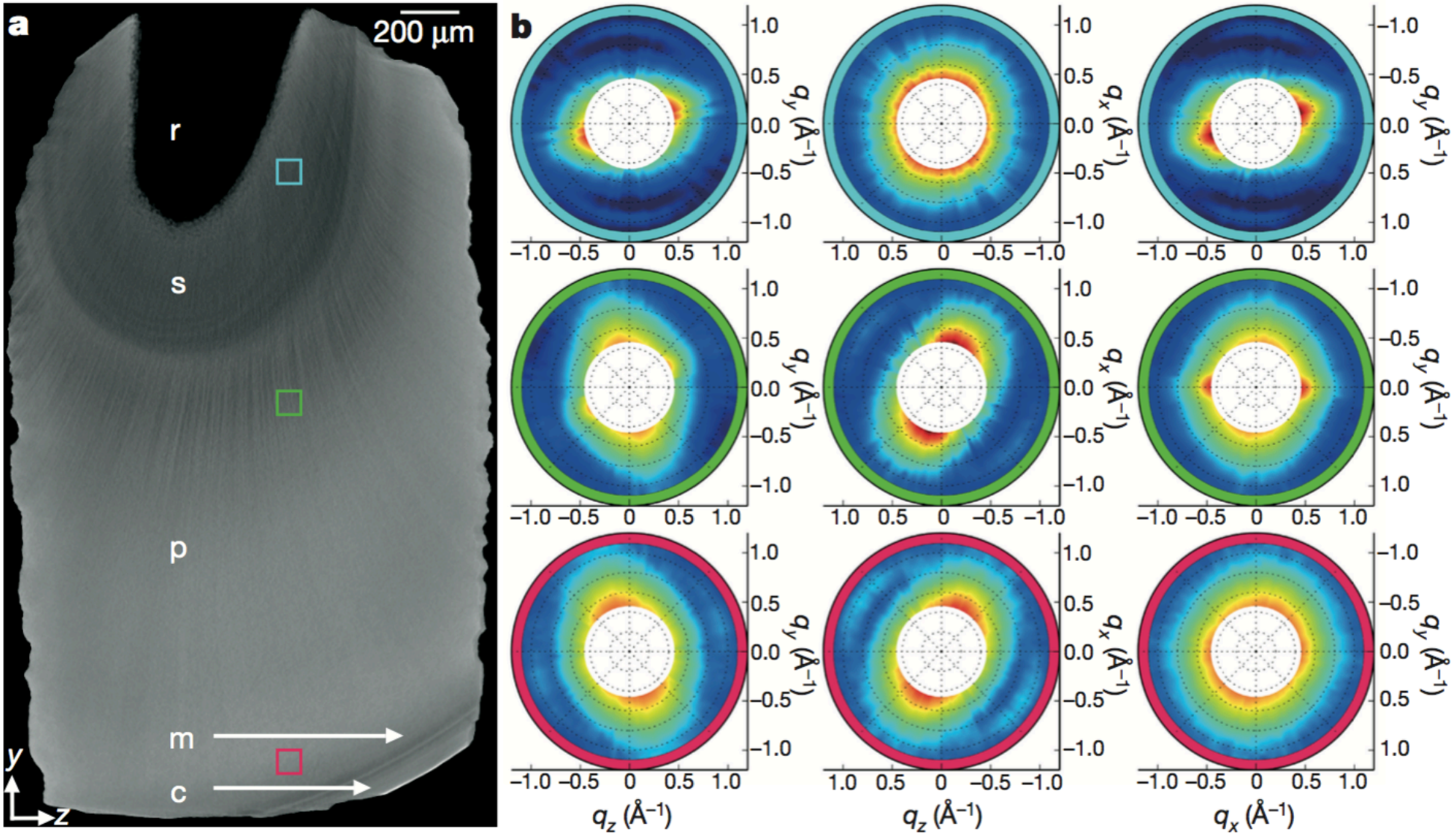

Myelin concentration, [arb. unit]
(c)
cc
ec
f
St
ac
ox
1
0.8
0.6
0.4
0.2
0
Myelin concentration, [arb. unit]
(d)
ec
cc
fi
Hb
ic
opt
1
0.8
0.6
0.4
0.2
0
Single layer thickness, [nm]
(e)
18.2
18
17.8
17.6
17.4
17.2
17
0
2
4
6
8
10
12
14
[mm]
Single layer thickness, [nm]
(f)
18.2
18
17.8
17.6
17.4
17.2
17
0
2
4
6
8
10
12
14
[mm]

Six-dimensional real and reciprocal space small-angle X-ray scattering tomography

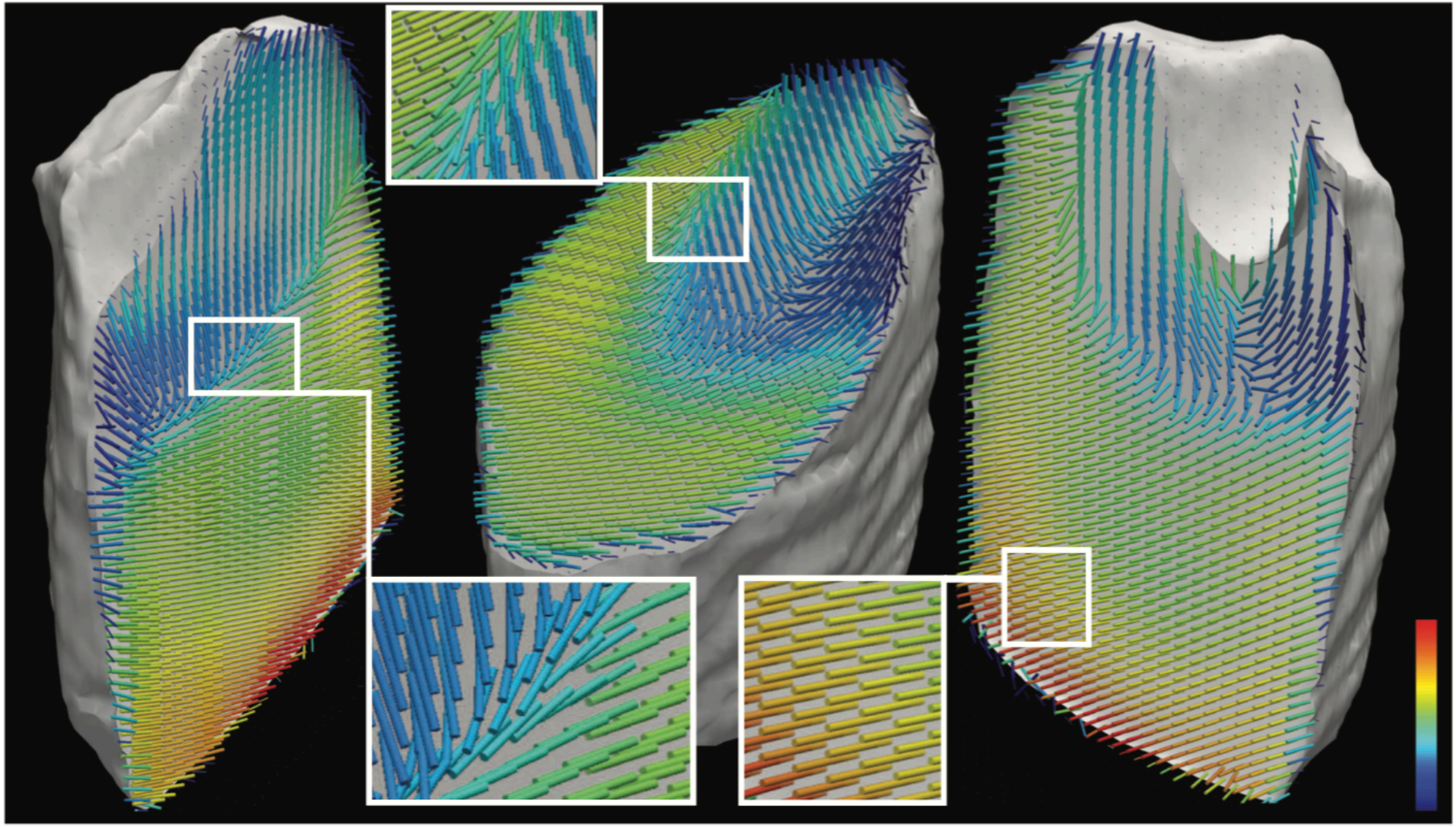
Florian Schaff[1], Martin Bech[2], Paul Zaslansky[3], Christoph Jud[1], Marianne Liebi[4], Manuel Guizar-Sicairos[4] & Franz Pfeiffer[1,5]



LUND UNIVERSITY



LUND UNIVERSITY



LUND
UNIVERSITY